science for a changing world

Oh, The Places You'll Go: Juvenile Salmon Migration Behavior from Rivers to Oceans

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ePTM Workshop
18 August 2017

Review of Migration Behavior

- Active migration - smolts
  - Migration rates
  - Biotic and abiotic drivers
- Holding behaviors
  - Diel migration patterns
  - Selective Tidal Stream Transport
- Navigation
  - Orientation in moving water
  - Compass (magnetic), Salinity, Celestial, Olfaction

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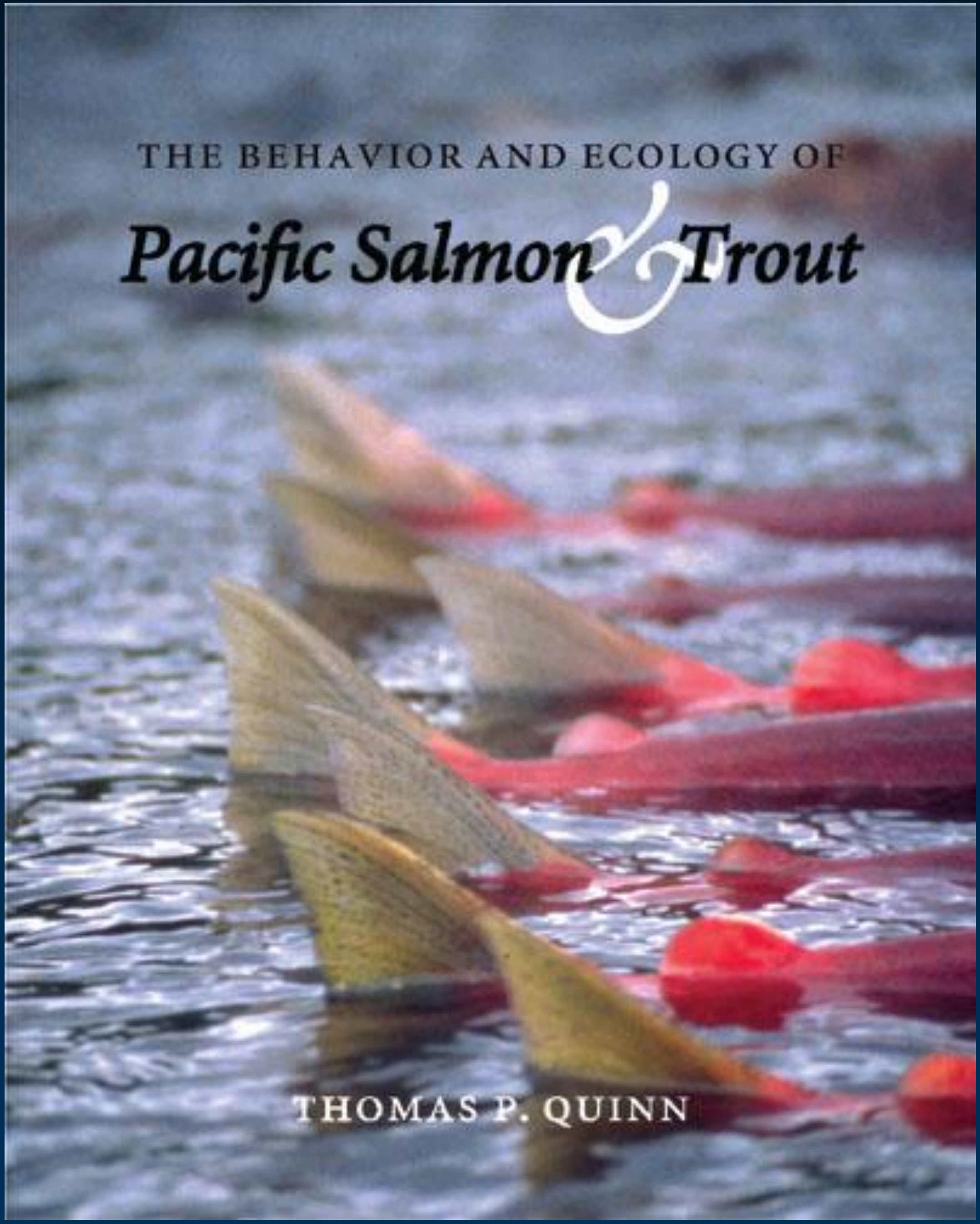


Chapter 13: Estuarine Residence and Migration

"Estuaries are inherently difficult environments in which to conduct behavioral and ecological research…"

"Because of these difficulties there is still considerable uncertainty regarding the roles that estuaries play in the lives of salmon."

Migration is a Time of Transition

Location:	River	Estuary	Ocean
Physiology:	Freshwater	Brackish	Saltwater
Habitat use:	Nearshore	Mid-Channel	Pelagic
Interactions:	Territoriality		Schooling

- Changing behavioral patterns
- Behaviors are context dependent:
  - Light, temperature, turbidity, water current, salinity, structure

Factors Affecting Migration Rates

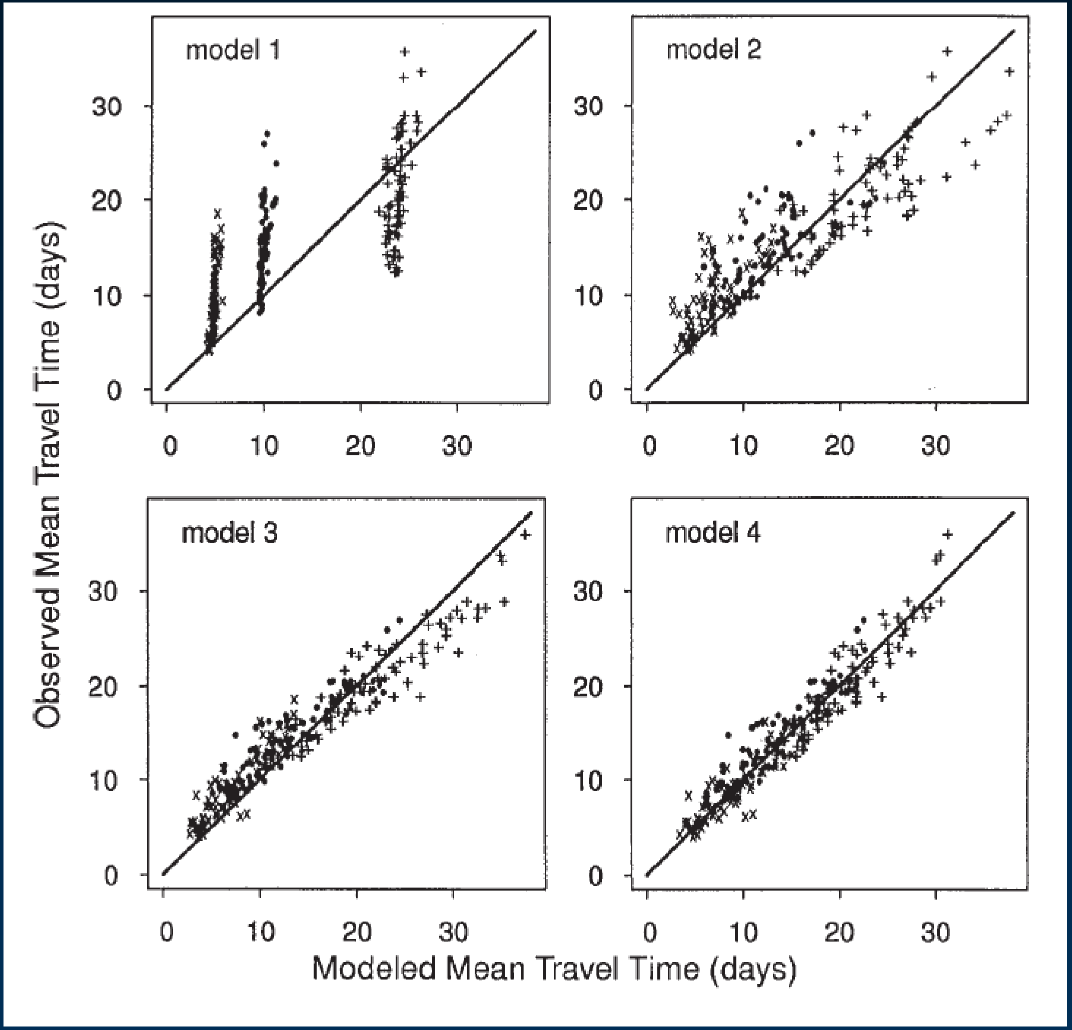
- Discharge / Water velocity
- Fish Size
- Time of year relative to mean run timing
- Indicators of smoltification

USGS

Multiple Factors Affect Migration

Zabel et al. 1998

Juvenile Chinook Salmon, Snake/Columbia Rivers



1) Mean only
2) Water velocity
3) Day of year
4) Time since release "experience effect"

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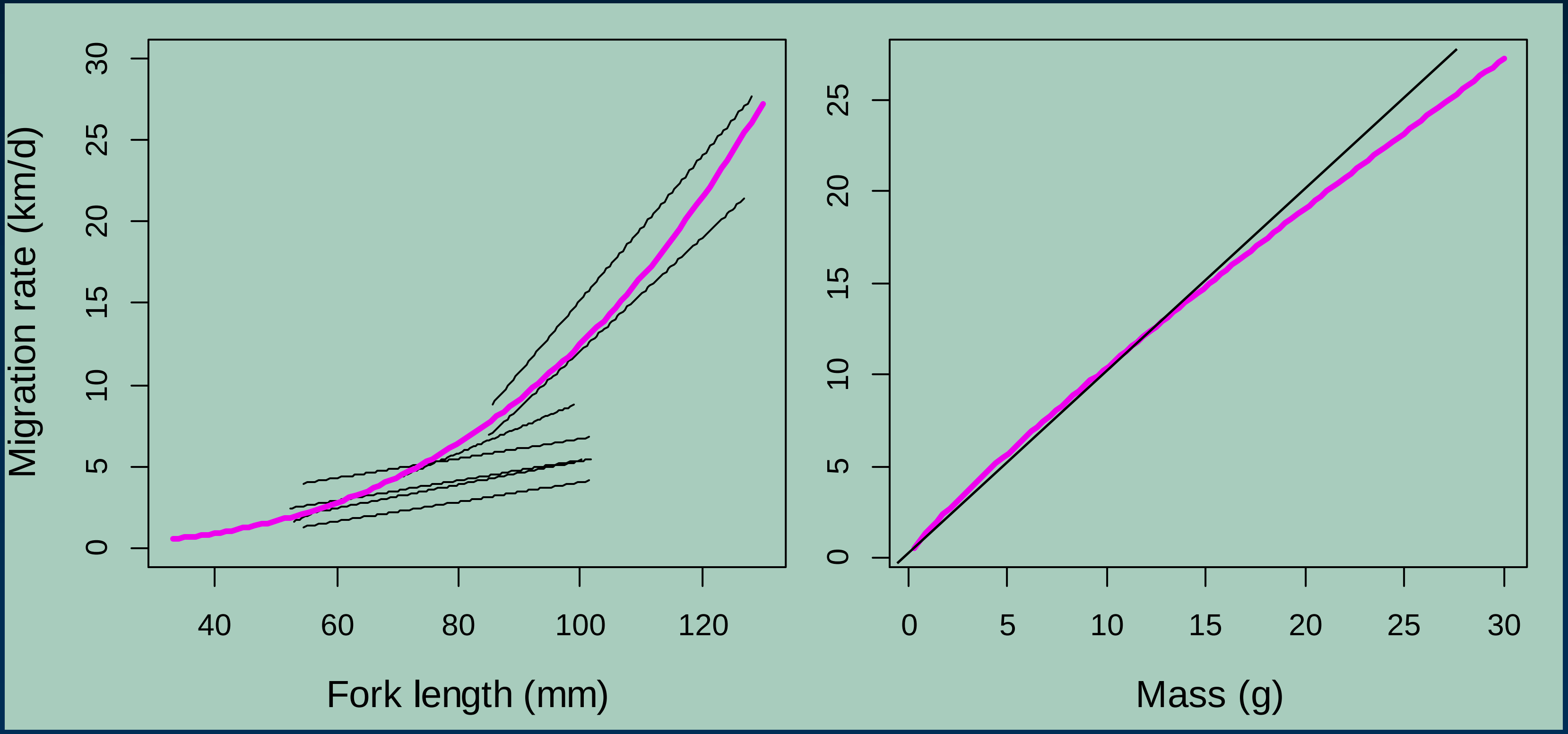
Fish Size and Migration Rate

Zabel 2002, Plumb 2012

Juvenile Chinook Salmon, Snake and Columbia Rivers

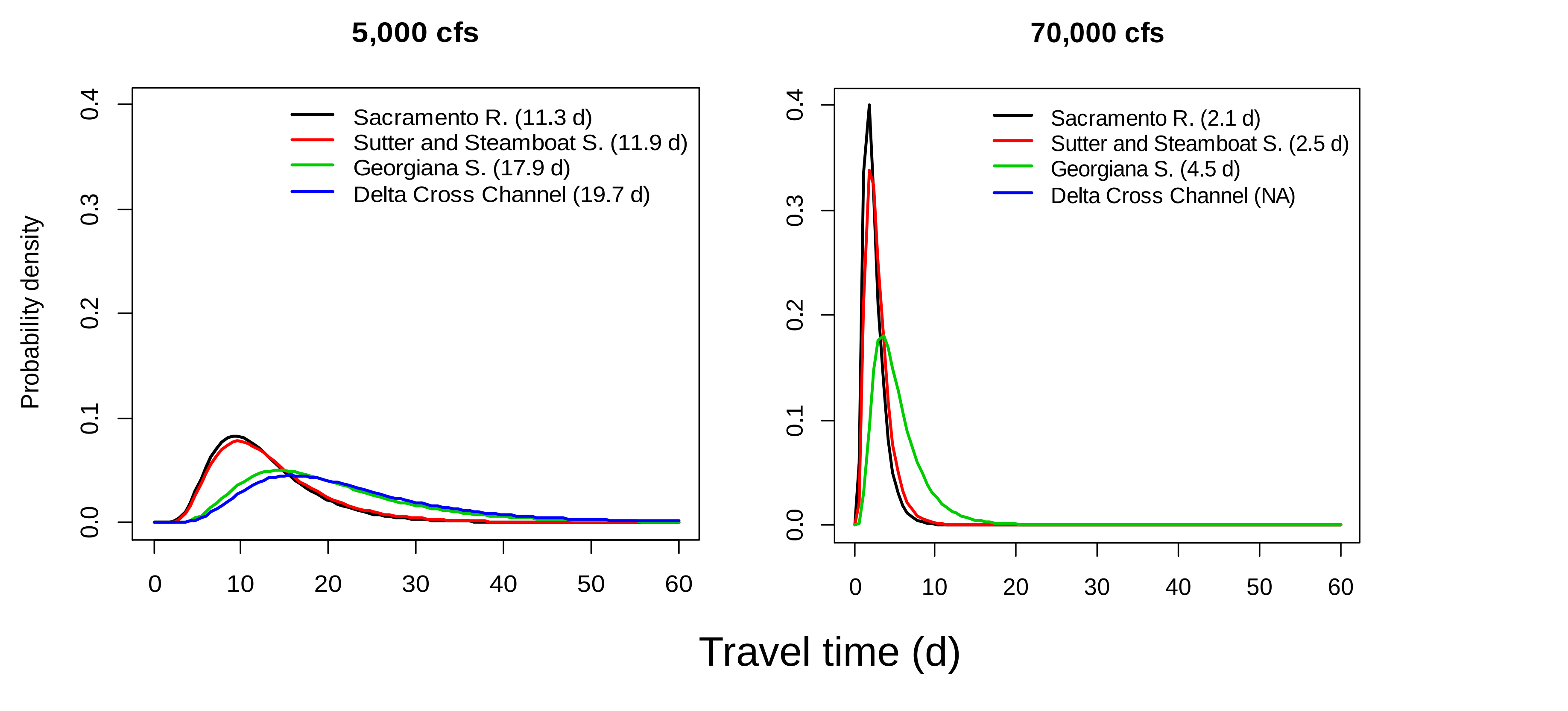
- $r = \ln(1.1) + \exp(-11.3)\,L^3$



Travel Times in the Delta

Perry et al. in review
Late-Fall Chinook from Sacramento River

Increased inflow reduces travel time in all reaches of the Delta



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Diel Activity Patterns

See Metcalfe 1998, 1999

- Nocturnal migration
  - But not all the time
- Determined by complex trade-offs between:
  - Growth (feeding)
  - Survival (predator avoidance)
- Minimize μ/f rule (mortality risk to food gained)
  - Nocturnal foraging should be preferred
  - But need to grow or migrate drives diurnal activity

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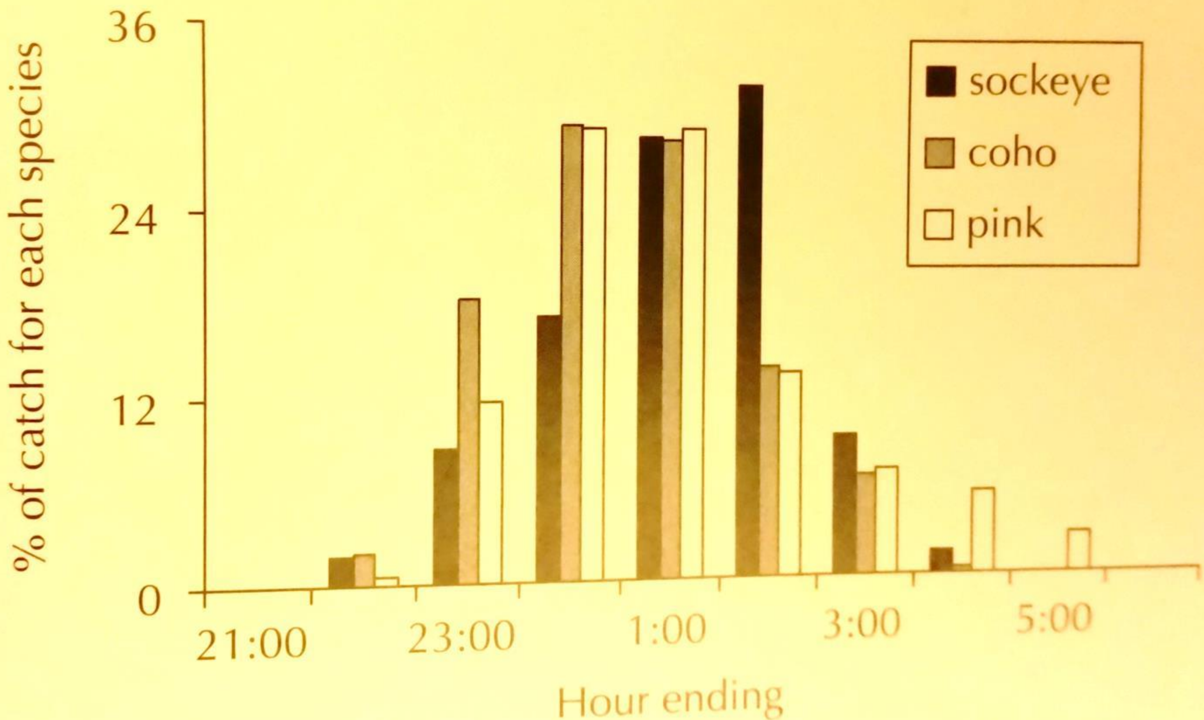
Nocturnal Migration

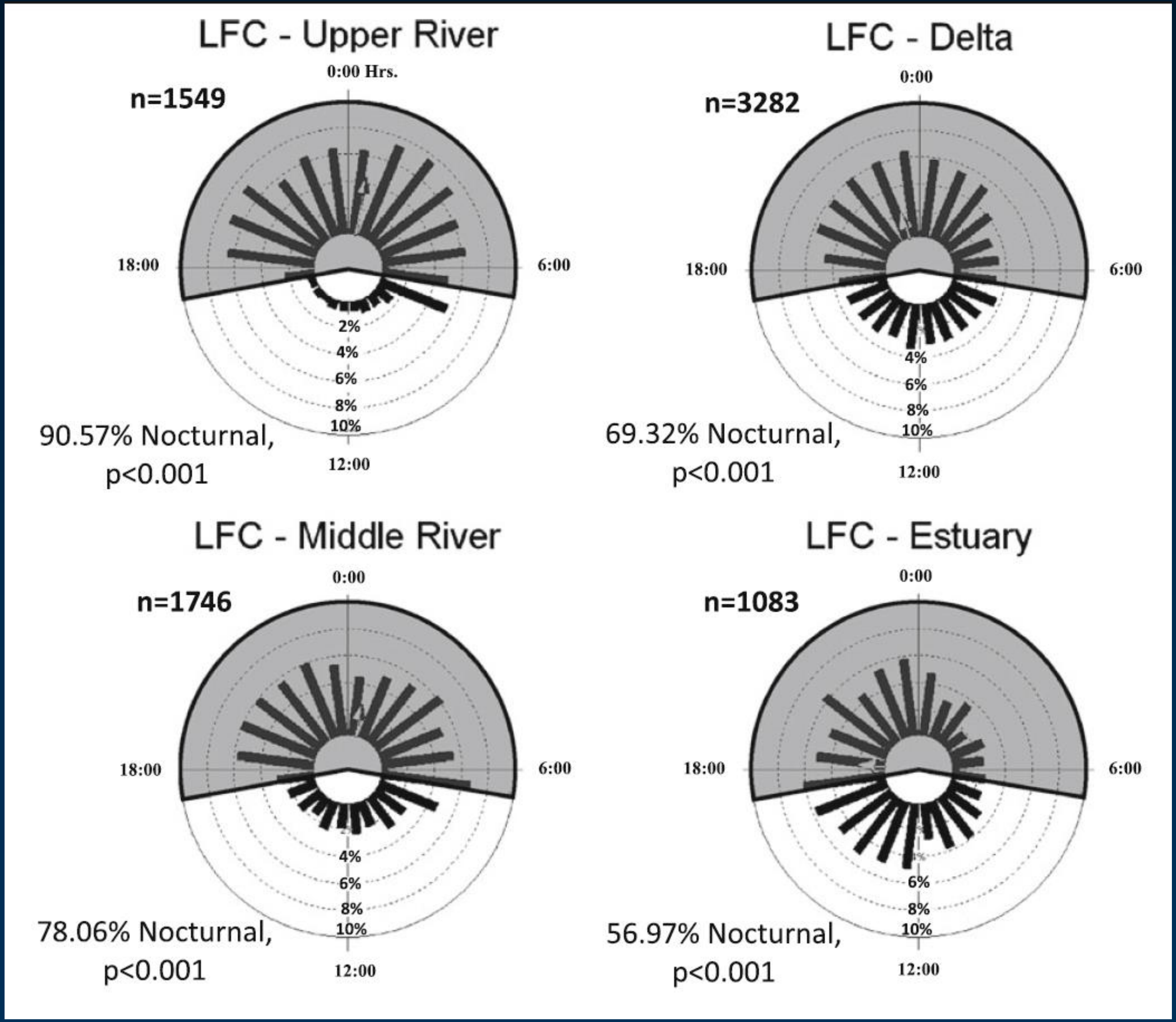
McDonald 1960 in Quinn 2011

FIGURE 12-5. Nocturnal downstream migration of juvenile salmon in the Lakelse River system, British Columbia (from McDonald 1960).



Sacramento River

Chapman et al. 2013
Late Fall Chinook



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Selective Tidal Stream Transport (STST)

- For Juvenile Salmon
  - High velocity regions on ebb tides
  - Low velocity regions on flood tides
    - E.g., eddies or shoreline

- Demonstrated for many larval species
  - Gibson et al. (2003)

- Exhibited by Delta Smelt
  - Bennett and Burau (2014)

Evidence for STST in Salmon

- Adult Sockeye (Quinn 2011)
- Juvenile Atlantic Salmon (Moore et al. 1995)

- Equivocal evidence in many cases
- Juvenile Atlantic Salmon (McCleave 1978)
- Juvenile Coho (Moser et al. 1998)

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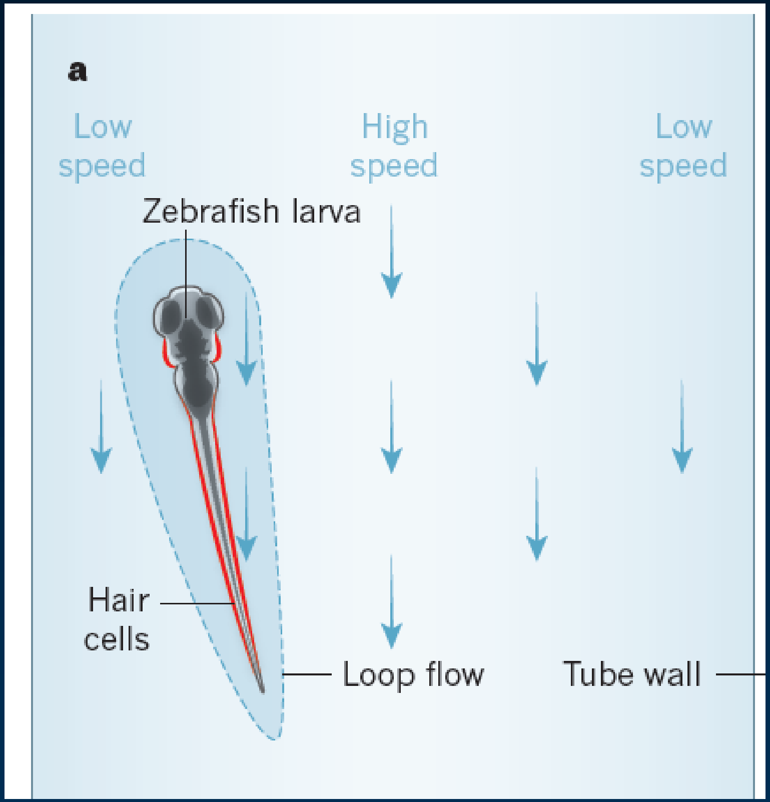
Orientation in Flowing Water

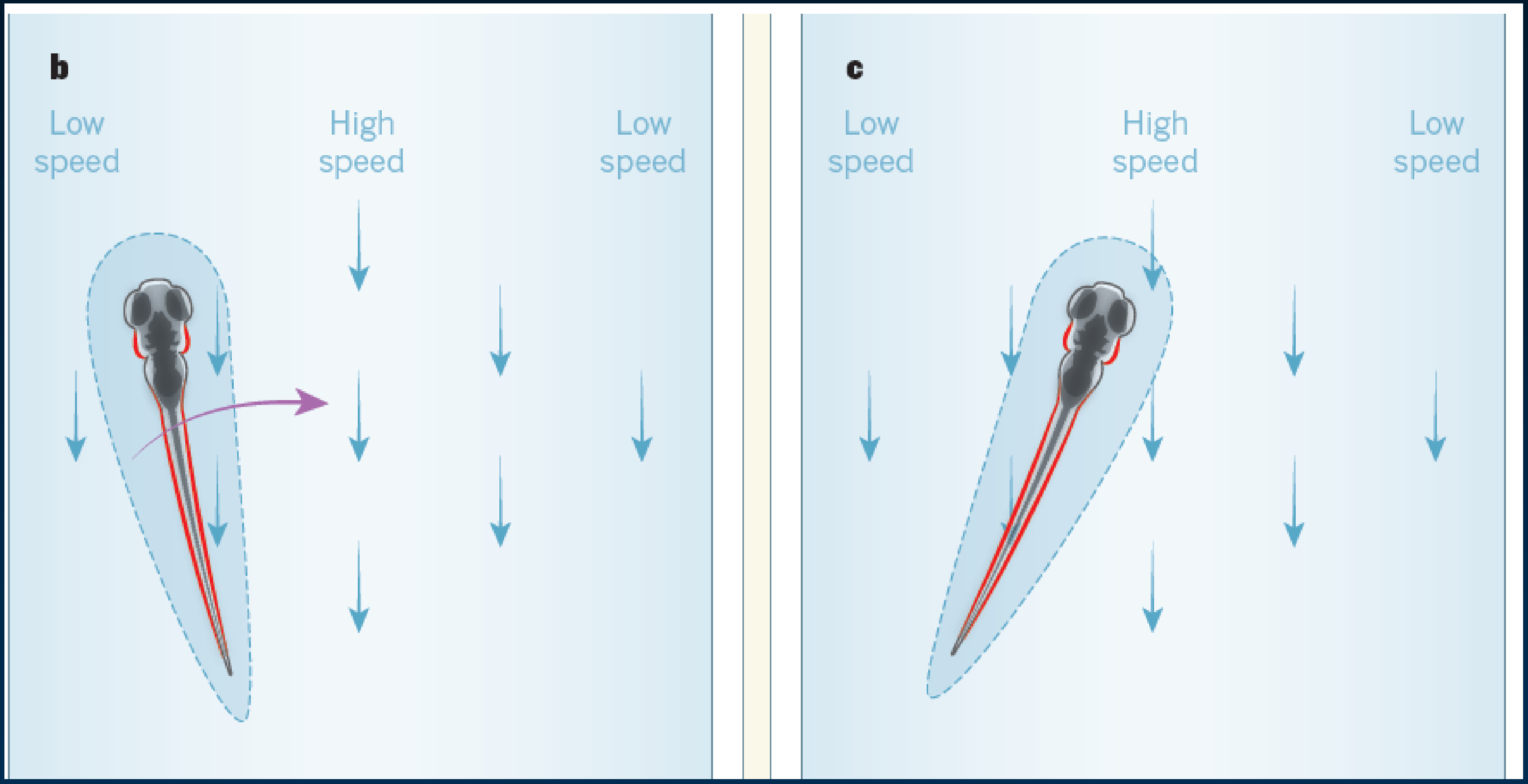
Dabiri 2017, Oteiza et al. 2017

- Fish sense velocity gradients surrounding body
- Change in gradient over time used for navigating



Orientation in Flowing Water

Dabiri 2017, Oteiza et al. 2017



Increasing gradient: turn away

Decreasing gradient: keep going straight

Orientation in Flowing Water

Dabiri 2017, Oteiza et al. 2017

- Explains how fish avoid obstacles in absence of visual cues
- Fish integrate velocity information over time

- Question: can juvenile salmon detect net flow direction in a tidal environment?
- Requires integration over longer time frame

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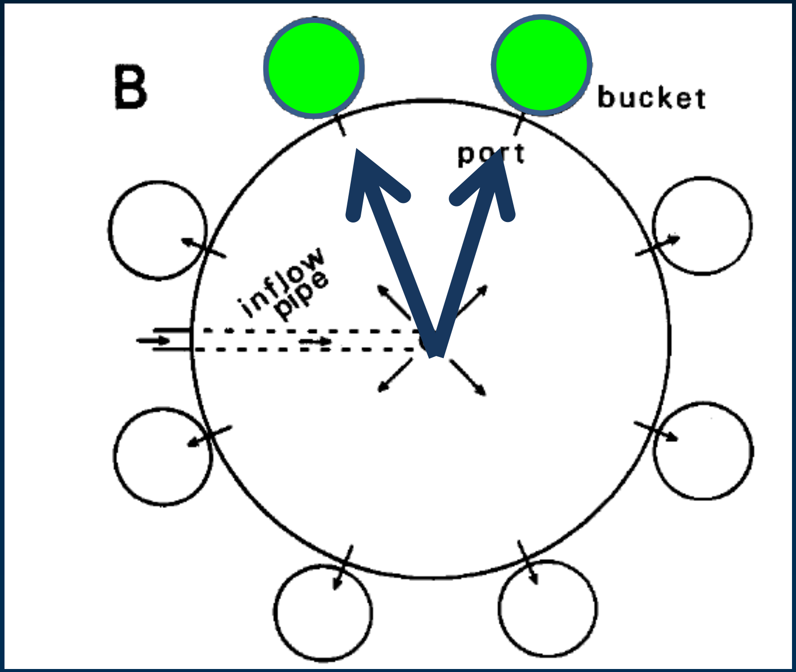
Compass Orientation

Quinn and Brannon 1982

- How to navigate in absence of flow cues?
  - E.g., Juvenile sockeye salmon in lakes



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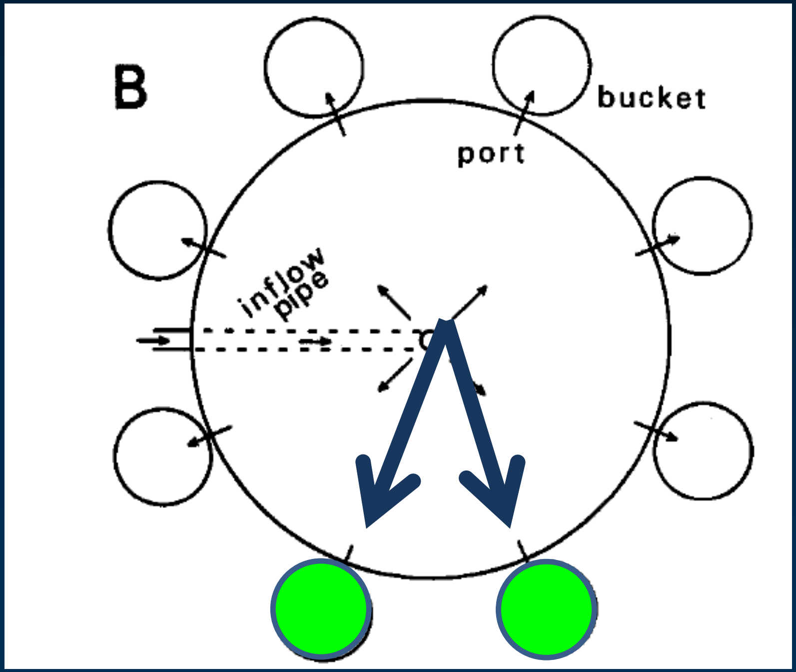

Other Navigational Strategies

Quinn 2011 and references therein

- Genetic
- Salinity Gradient
- Celestial (direction of polarized light)
- Olfaction

- Some evidence for each behavior

Take Home Points

- Wide array of migration strategies
- But behaviors and navigation strategies vary
- Driven by complex tradeoffs between growth, survival, and physiological state
- Mediated by environment
  - Temperature, turbidity, season
- No single set of behavioral rules

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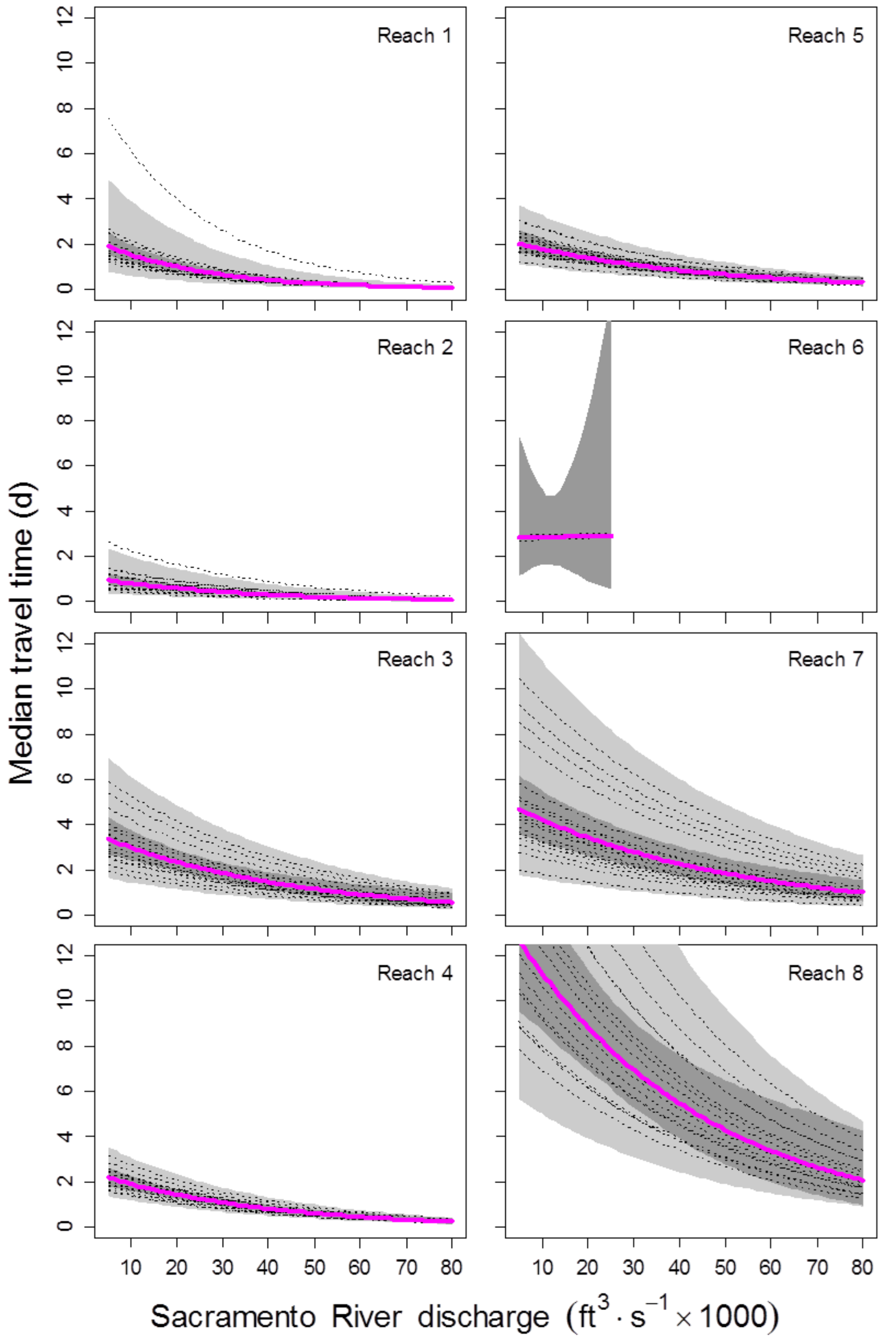

Pink line = Median relationship
Dotted lines = release-specific relationship
Gray shading = 95% CI

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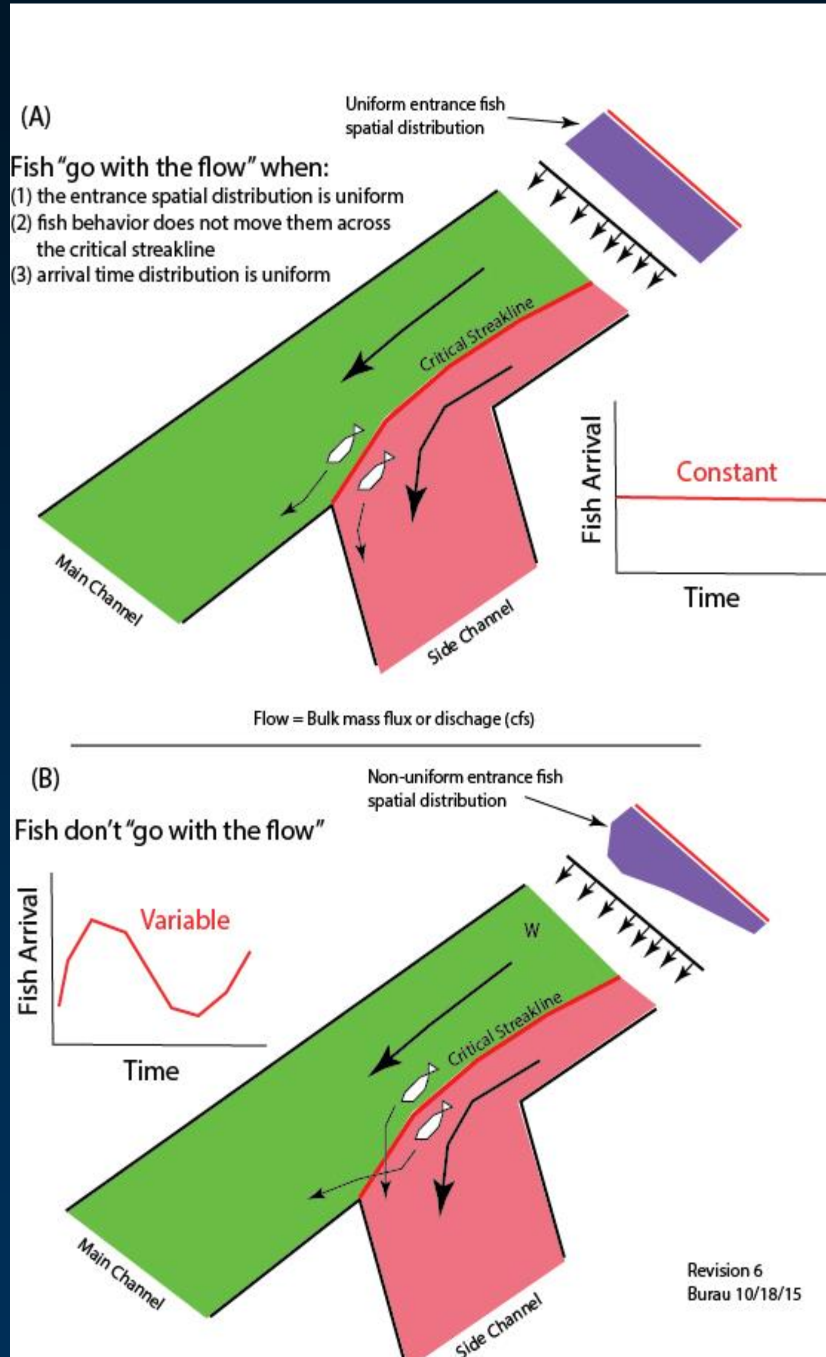
(A)
Uniform entrance fish spatial distribution
Fish "go with the flow" when:
(1) the entrance spatial distribution is uniform
(2) fish behavior does not move them across the critical streakline
(3) arrival time distribution is uniform
Critical Streakline
Fish Arrival
Constant
Time
Main Channel
Side Channel
Flow = Bulk mass flux or dischage (cfs)
(B)
Non-uniform entrance fish spatial distribution
Fish don't "go with the flow"
Fish Arrival
Variable
Time
Critical Streakline
Main Channel
Side Channel
Revision 6
Burau 10/18/15